USAELRDL Technical Report 2286

INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES

W. W. Malinofsky

J. Newberg

G. C. Sands

September 1962

UNITED STATES ARMY

ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

FORT MONMOUTH, N.J.

$2.60

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

FORT MONMOUTH, NEW JERSEY

September 1962

USAELRDL Technical Report 2286 has been prepared under the supervision of the Director, Electronic Components Department, and is published for the information and guidance of all concerned. Suggestions or criticisms relative to the form, contents, purpose, or use of this publication should be referred to the Commanding Officer, U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey, Attn: Chief, Microwave and Inductive Devices Branch, Electronic Parts and Materials Division.

J. M. KIMBROUGH, JR.
Colonel, Signal Corps
Commanding

OFFICIAL:
HOWARD W. KILLAM
Major, SigC
Adjutant

DISTRIBUTION:
Special

INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES

W. W. Malinofsky

J. Newberg

G. C. Sands

DA TASK NR 3A99-15-001-01

ABSTRACT

Eleven commercial magnetic ferrite types from two companies were investigated for possible long-term effects due to exposure to neutron irradiation simulating a nuclear burst. That is, the materials were exposed to very high intensity irradiation (approximately 10^{17}n/cm^2/sec) for a very short period (a pulse of 80 microseconds at half-height). The exposed samples, as well as controls, were measured for magnetic, crystallographic, and resistivity changes. Specific magnetic properties examined were L,Q, B_m, B_r, and H_c, as well as electrical resistivity. The specific crystallographic properties investigated were lattice-defect production, redistribution of the metal atoms, and changes in lattice symmetry or size. Magnetic and electrical effects due to ambient temperature, etc., were observed in both control and irradiated cores as random changes. In order to isolate these effects from irradiation effects, special control tests were ultimately required. The random nature of the changes necessitated a statistical approach, as well as maximum precision of measurement. The determination of this precision was thus of prime importance. After determining the magnitude of these miscellaneous effects and subtracting them out, it was concluded that no changes were observed caused by the neutron irradiation.

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

FORT MONMOUTH, NEW JERSEY

CONTENTS

ABSTRACT	
INTRODUCTION	1
NEUTRON IRRADIATION SOURCE	1
RESISTIVITY OF COIL WIRE	2
MAGNETIC PROPERTIES OF FERRITES	2
FERRITE RESISTIVITY	5
CRYSTALLOGRAPHIC PROPERTIES OF FERRITES	8
CONCLUSIONS	11
RECOMMENDATIONS	11
REFERENCES	11
APPENDIX	12

FIGURES

1. Jig, (disassembled) for Applying Voltage Probes and Current to Ferrite Toroidal Core (4 pages)	14
2. Daily Variation in Resistance with Ambient Temperature	15

TABLES

1. Inductance and Q Measurements	16-19
2. Hysteresis Loop Measurements	20
3. Resistance Changes in Ferrites	21
4. Half-Widths of X-Ray Diffraction Peaks of Irradiated and Control Samples	22
5. Relative Intensities of X-Ray Diffraction Peaks for Irradiated and Control Samples	23
6. Positions of X-Ray Diffraction Peaks for Irradiated and Control Samples	24

INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES

INTRODUCTION

Not a great amount of information[1] is available concerning the effect of neutron irradiation on the magnetic properties of ferrites. Practically nothing can be found in the literature concerning the resultant crystallographic and electrical effects in these materials. What has been done has, in all cases, involved relatively low irradiation intensities. Moreover, the materials were generally exposed for very long periods, often days at a time. These conditions do not approximate a nuclear burst.

All this is in sharp contrast to the conditions of the experiments discussed in this report, where neutron pulses of orders of magnitude greater intensity but of orders of magnitude lesser duration were available. In the above-mentioned work of other experimenters, considerable changes in ferrite magnetic properties were reported. The question which will be answered in this investigation is whether or not similar or worse changes result under the conditions of this experiment—these conditions being of military interest since they more closely approximate those of a nuclear weapon explosion than do those of any of the earlier reported studies.

The samples in this investigation were commercial ferrite cores of many types, their application to radio-frequency communication encompassing frequency bands from 1 kc/sec to as high as 200 Mc/sec, all of importance to Electronics Command devices and equipments.

In the sections to follow, the following aspects of the investigation will be described in detail: the neutron irradiation source, the magnetic properties, the electrical resistance, and the crystallographic properties. Although presented separately, the last three aspects of the investigation are closely related, since the production of crystallographic defects, for example, by the neutron irradiation would decrease the initial permeability as well as the electrical resistance, and the quality factor Q would also diminish. The coercive force, on the other hand, would tend to increase. Thus, this investigation sought both to find long-term changes, if any, which might occur in the properties of ferrites due to pulsed neutron irradiation, and to interrelate (or cross-check) these effects from more than one point of view.

NEUTRON IRRADIATION SOURCE

The source for the neutron irradiation utilized in this investigation was the Godiva II Reactor located at the Los Alamos Scientific Laboratories at Los Alamos, New Mexico. This reactor will deliver a neutron pulse 80 microseconds wide at half-height, giving an integrated neutron flux of 10^{13} nvt (neutrons per square centimeter) at the reactor surface. The average neutron flux is approximately 10^{17} neutrons per square centimeter per second, much higher than that obtainable from other reactors. Thus, this more closely simulates a nuclear weapon explosion than does any other source. The test samples used in this investigation were situated some distance away from the reactor surface, however, and consequently received somewhat less than the above dosages. A single dosage amounted to about 10^{12} nvt, while the accumulated dosages were equal to almost 10^{13} nvt. These amounts include both fast and thermal (≤ 0.025eV) neutrons. The thermal neutron flux of about $2 - 5 \times 10^{9}$ nvt did not vary with the position of the samples, whereas the fast neutron flux fell off inversely as the square of the distance from the center of the reactor. The latter flux was measured by a sulfur activation technique, and the former by a gold and cadmium foil method. Using a film dosimetry technique, the accompanying gamma radiation was determined to be about 9% to 10% of the neutron dose.

RESISTIVITY OF COIL WIRE

A Kelvin bridge was used to measure the resistance before and after neutron irradiation of No. 29 HF (enamel-insulated) copper wire, taken from the same spool used for the windings of the ferrite cores utilized in this investigation. A 5-ft length was employed, with copper lugs soldered to the ends to prevent any variation in effective length during each attachment to the bridge. The Kelvin bridge was maintained and the measurements carried out in an air-conditioned environment. The precision of measurement was about 1/4%. The difference in resistance values measured before, after, and again one year after the neutron irradiation was within this tolerance. In any case, the effect on Q of this small variation would not be significant in the practical application. (It might be noted that in other samples, changes in resistance due to cold-working of the wire were observed.) The conclusion drawn is that no significant effect due to irradiation of this magnitude occurred in the copper wire of the type used in winding the magnetic coils.

MAGNETIC PROPERTIES OF FERRITES

General

This part of the experiment was designed to determine the long-term changes in magnetic properties due to irradiation, as well as to correlate them with other properties. For example, in order to explain any change in quality factor Q of a wound core (Q equals $L\omega/R$), measurements of the parameters involved in the inductance L and the loss R were also made. In the case of L, only the initial permeability μ_o of the core material had to be measured, whereas R could be affected by changes either in the losses in the core material or in the resistance of the copper winding, or both. Therefore, measurements of changes in resistivity of both the ferrite core as well as the copper wire were also made. The coercive force H_c was another magnetic property that was monitored, since it could be correlated with μ_o; i.e., generally the higher the coercive force, the lower the μ_o. Saturation magnetization B_m and remanence B_r were also measured at the same time, being evaluated along with H_c from hysteresis-loop traces. Many of these properties can be correlated with the crystallographic and electrical resistance studies reported in a later section of this report.

As it turned out, a major problem of this part of the investigation was in accounting for changes that occurred not only in the irradiated samples but in the control samples as well. Thus, precision of measurement was an important factor to be determined. Changes beyond this precision level were of a random nature so that a statistical approach was necessary.

Special care was taken in the investigation to account for statistical fluctuations in the measurements. Special control cores were used to determine any possible effects of humidity on the measurements as well as of day-to-day variations in the cores or measuring apparatus. Other control samples took into account possible effects of transporting the test samples to the test site, i.e., shock, vibration, temperature, humidity, and stray magnetic field effects of the trip. In general, there were twice as many control samples as test samples. The ultimate purpose of this was to strictly define the limits of change, or conversely, stability, detected as a result of the irradiation.

Ferrite Core Samples

Sample cores were chosen from production, on-the-shelf, stocks of two well-known manufacturers of magnetic ferrites. The compositions included both the manganese-zinc and the nickel-zinc varieties of ferrites, the latter containing some cobalt usually, and sometimes copper. These cores were selected to cover a broad range of frequencies applicable to communication devices, approximately 1 kc to 200 Mc. There were eleven types of materials, all variations of the manganese-zinc and nickel-zinc ferrite compositions used in the test. For the purposes of this requirement, these various types have been numbered from 1 to 11.

Generally, six toroidal cores of each commercial type of ferrite were used for the measurements of initial permeability and Q, and six for hysteresis-loop measurements (B_m, B_r, H_c). Two samples of the six served as "test samples," i.e., samples exposed to the reactor radiation. Two others remained in the laboratory as control samples, and were called "lab controls." Two others were transported to Los Alamos with the test samples and experienced the same conditions (i.e., shock, vibration, temperature, humidity, and any stray magnetic fields), except that they were kept about 1/4 mile from the reactor site. These were dubbed "site controls." There were, therefore, four control samples for every two exposed test samples.

Magnetic Measurement Methods

AC Properties: Changes in the quality factor Q and inductance L of the wound test cores were measured by means of a Boonton Model 260-A Q-Meter. Q was read directly, while variations in L could be measured by observing changes in capacitance C, read directly on the Q-Meter. In this case, $L\omega$ is equal to $1/(C\omega)$; and for small variations ΔL in L, the relative change $\Delta L/L$ is equal and opposite in sign to $\Delta C/C$. The method followed was to wind each toroidal core with sufficient turns of either No. 24 or 29 American Wire Gauge enamel-coated copper wire to resonate with the internal capacitor of the Q-Meter at three frequencies, in turn. These frequencies were chosen to fall within the optimum frequency range of the core material. (It was necessary at times to add an external precision General Radio Type 722-N Capacitor to the capacitance terminals.) The sample coil leads were kept short to minimize lead inductance.

The actual measuring procedure consisted of taking five readings each of Q and capacitance C, and calculating the average values. The coil leads were alternately reversed on the Q-Meter terminals with each reading to average out any possible variations in lead inductance or contact resistance. This procedure was followed both before and subsequent to irradiation. In addition, the mean deviation within a set of readings was calculated to give a measure of the precision, or repeatability, of the measurement. This procedure was then repeated at each of the three frequencies used for the given sample type. See Appendix for determination of Q-Meter precision (about 1/2%).

DC (Hysteresis-Loop) Properties: Changes in such hysteresis-loop characteristics as maximum flux density B_m, remanence B_r, and coercive force H_c were monitored with the use of a semiautomatically recording fluxmeter, commonly known as a dc loop-tracer. It is the general type described by Cioffi.[2] Each sample toroid was wound with a 20-turn primary and a 300-turn secondary. Direct current hysteresis curves were traced out for each sample, both before and after irradiation. From these curves, values of B_m, B_r, and H_c were measured for each toroidal core, and any changes determined. See Appendix for determination of loop-tracer precision.

Magnetic Measurements Data and Results

AC Properties: Table 1 presents the differences in L and Q values measured before and after the neutron irradiation. Also listed is the value of the mean deviation (D_L, D_Q) for either the initial or final value, whichever is greater, to provide a measure of the repeatability or precision of each measurement. A change within the precision of measurement is not considered significant. On the last page of Table 1 are listed certain ferrite cores which were given multiple exposures to neutron radiation within the same day. Thus, the total dosage was increased by a factor of about 8 over that received by the other samples. This was done in order to enhance any effects that might occur due to the irradiation.

Before discussing the results, it should be pointed out that certain important limits of variation (namely, 4% in L and 15% in Q) due to non-nuclear factors were determined in special control tests (see Appendix) and will often be referred to in the following. Next, the "lab" and "site" control samples will be discussed. Examination of the results in Table 1 shows that, in the case of the control samples maintained within the laboratory, $\Delta L/L$ variations up to the same limit of 4% were measured, as well as $\Delta Q/Q$ changes up to 10%. In the case of the control samples transported to the Godiva site, the variations exhibited in $\Delta L/L$ again never exceeded 4%, while the $\Delta Q/Q$ changes were less than 15% except in the case of one of the Type 2 cores. (Even this ferrite experienced only a 19% change; moreover, the other Type 2 site control sample changed less than 3%.) Thus, the control cores varied considerably more than considerations of precision would allow, yet not beyond the range of variation due to non-nuclear factors.

Finally, of the 30 test samples irradiated, only five exhibited changes exceeding the above statistical limits obtained from the special control tests previously mentioned. They were the following: one Type 4 ferrite sample receiving a multiple exposure showed a $\Delta Q/Q$ change of 20% (although the other test core, as well as the site control core, changed by only 13%); both test cores of Type 1 ferrite exhibited a $\Delta Q/Q$ change of 27% measured at 170 kc (but was not consistent with the 4% and 12% changes found in the cores at 90 and 126 kc, respectively); and finally, both test cores of Type 11 ferrites receiving the multiple exposure showed a $\Delta L/L$ change of 6% at 250 kc, over the 4% "limit," being the only cores to do so (although this was not entirely consistent with the changes measured at other frequencies).

In considering the validity of the above-mentioned apparent changes, it is first of all observed that they occurred only in the cases where Q was low. (It should be mentioned that no attempt was made in the test to optimize Q.) For example, the Q of the aforementioned Type 4 ferrite changed from 15 to 12 or 20%· but since Q was read to the nearest whole number, ΔQ was nearly equal to the sum of the reading errors (2) of the two measurements. This was also true in the case of the Type 1 ferrite, where Q changed from 11 to 14. Moreover, in view of the fact that the above deviations in Q occurred at the very lowest portion of the meter scale (10 to 250) where the reliability is no better than about ±7% (manufacturer quotes ±5% accuracy at full scale, 250), it would not be justified to accept the above deviations in Q of only 2 or 3 as real changes due to neutron irradiation.

Further, as will be shown later in the resistivity investigation, ambient temperature changes between the initial measurements and those taken after the irradiation would have caused such variations in the ferrite properties. This would be particularly true for the very materials which exhibited these apparent changes: Types 1, 4, and 11 all being low Curie Point ferrites with fairly large temperature coefficients of initial permeability of 0.3, 0.7, and about 0.6%/°C, respectively. These coefficients would produce about the same changes in Q. In the case of Type 11 material, a 5°C difference in temperature between the initial and final measurements (which were separated in time by about a month) would produce a $\Delta L/L$ change of 3%. This could easily occur, especially if the initial and final readings were taken at different parts of the day. This 3% change superimposed on the 4% range of variation of $\Delta L/L$ found for the special control core, Type 10, in the special test conducted at constant temperature (described in the Appendix) is sufficient to account for the 6% $\Delta L/L$ change exhibited by the Type 11 cores. Therefore, for the above reasons, it is concluded that all the changes in these low-Q materials are not due to neutron irradiation.

DC Hysteresis-Loop Properties: Next to be considered are the hysteresis-loop properties, as shown in Table 2. The key to interpreting the results of this experiment lies in the observation that again some unknown randomizing influence is present. This can be seen from the fact that the laboratory control samples, normally expected to be the least changed of all the samples, often varied more than the others. Again, in some cases, the site control samples varied more than the irradiated cores. Moreover, two cores of any of the three categories may change in opposite directions. Thus, only a random influence could account for this. That these variations exceed the precision inherent in the instrumentation is seen from the 17-day check on the repeatability of measurement, given in the Appendix.

A measure of this effect may be obtained by a statistical analysis of the control samples as a group. The maximum variations in each property thus found are as follows: in B_m, 15%; in B_r, 29%; and in H_c, 46%. The irradiated samples as a group, on the other hand, experienced the following maximum variations: in B_m, 13%; in B_r, 15%; and in H_c, 35%. Thus, the irradiated samples showed no greater maximum variations than those of the control samples.

Table 2 also shows a comparison between changes found in H_c and the maximum variation possible due to the experimental reading error ΔH_r of the recorder charts. This is necessary in the case of H_c, since the reading error is relatively large, due to the fact that narrow loops resulted from the choice of scale factors for applied fields necessary to approach saturation of the material. By the total reading error shown is meant the sum of the maximum reading errors of the initial and final values. Cases where the variations in H_c exceeded the total reading error were distributed among both irradiated and control cores. But in only one case (ferrite Type 1) did a test core experience a greater variation than its corresponding control cores, and then by less than half of the total reading error. Less than twice the reading error is not considered a significant change, especially since some control cores experienced changes greater than twice the reading error. In addition, the other irradiated core of ferrite Type 1 did not show a change exceeding the total reading error. Thus, it is concluded that no significant change in the dc hysteresis-loop properties was experienced due to the neutron irradiation.

Summary of Magnetic Results: The investigation of the magnetic properties of present commercial ferrites showed no changes in L, Q, B_m, B_r, or H_c which could be ascribed to exposure to neutron irradiation. A random variation in properties did generally take place throughout the list of samples (control as well as irradiated cores): i.e., up to 6% in L, 27% in Q, 15% in B_m, 29% in B_r, and 46% in H_c. However, in the last three properties mentioned, the maximum changes were exhibited by the control cores. In the first two properties, L and Q, the control cores exhibited nearly the above amount of change, with 4% and 19%, respectively. The remainder was accounted for by considerations of ambient temperature changes and the fact that the samples changing most were consistently low-Q materials (increasing the relative reading error). (Specially controlled tests in the laboratory, described in the Appendix, showed that some random change (about 5%) in the properties of ferrites did exist, which could not be ascribed to the measuring equipment or any other known cause.) Moreover, even if the above listed changes in L and Q were due to irradiation, the effects could be disregarded from a practical point of view, since the Q (being so low in those cases) would require a broad-band circuit application anyway that would not be sensitive to small changes in L and Q.

FERRITE RESISTIVITY

General

The resistivity of the ferrite cores was of interest since a change in the value of this property would be indicative of lattice defects produced by the neutron bombardment, and this could then be correlated with the changes in the values of the crystallographic and magnetic properties. In actuality, the measurements to be described were of changes in resistance, rather than in resistivity, since the former is linearly related to the latter and both will evidence the same relative change.

The Measurement Instrumentation

The resistance measurement method was devised to overcome the problems of contact resistance as well as the generally large values of resistivity encountered in ferrite materials. It is basically a four-probe technique, adapted to meet the geometry involved in the measurement of toroidal samples. After removing about a 30° pie-cut in the toroidal core with a diamond saw and grinding the cut surfaces with silicon carbide paper, tinfoil electrodes were attached to these cut ends with petrolatum. These then acted as the current electrodes, and were connected across the terminals of a 45- or 225-volt battery. These voltages were required because of the high resistances involved, especially for the Types 3, 5, and 6 ferrites. Two needlelike probes impinged on one of the flat circular surfaces of the toroid and acted as the voltage probes (see Fig. 1). They were adjustable and could be positioned on a mean diameter of the circular toroid, their location being approximately equidistant from the current electrodes to insure uniform electric fields in the vicinity of the probes. The sample and probes were held in position by means of a special jig constructed of fiber-glass silicone laminate (resistivity equal to 10^{10} ohm-cm) and teflon (resistivity greater than 10^{15} ohm-cm). The former material comprised most of the jig, while the latter under pressure from a spring was used in wedge-form between the current electrodes to maintain good contact between the tinfoil electrodes and the sample. These materials were chosen for their high resistivities (ferrites range to about 10^{8} ohm-cm), so as to prevent any error due to leakage current through the jig. The voltage was measured by connecting the voltage probes to a Keithley Electrometer, Model 200, with Voltage Divider (10:1). The electrometer was used in order to take advantage of its high input impedance (greater than 10^{14} ohms), since an ordinary voltmeter was found to have an input impedance low enough to affect the reading. A Keithley Electrometer, Model 210, with a decade shunt box was used to measure the lower currents experienced with the more resistive Types 3, 5, and 6 materials, while a General Electric milliammeter, Model DP-2, was used for the higher currents obtained with the less resistive Types 1, 2, 4, and 11 ferrites. As a precaution against surface conductivity, due to grease or moisture, the samples were cleaned with methyl alcohol and then kept dry by storing in a desiccator before any measurements were taken.

Measurement Procedure.

The resistance measurement procedure was as follows. After preparing a sample of each of the above-named ferrite types in the manner outlined, a sample was placed in the jig and the voltage probes positioned on a mean diameter of the toroidal core, approximately equidistant from the current electrodes. (The diameter of each sample had been determined and inscribed on the core by means of a "trihead." Then the outer and inner diameters were measured with a millimeter rule and the two points on the line delineating the mean diameter were divided. This distance was also set and locked between the voltage probes by means of adjustments on the jig.) Simultaneous readings of voltage and current were then made. This process was repeated for new voltage probe positions slightly displaced circumferentially from the first ones, and lying on another diameter having a small angular displacement from the first. (Slight radial displacement of the probes was found to have no significant effect on the measurement.) In this manner, three sets of readings were obtained in all. This was done to average out any possible effects due to surface variations on the sample. From the above readings, the value of resistance R was calculated for each set of readings and the average R of the three values computed. Four cores of each of the ferrite types 1, 2, 3, 4, 5, 6, and 11 were measured in this way. Two test cores of each with their tinfoil current electrodes attached were placed in paper envelopes and paper-taped to a hemispherical aluminum framework and then shipped to the Godiva site for neutron irradiation. Thereafter, the resistance measurements were repeated precisely as before. The remaining two cores of each type, which were not irradiated, served as control cores. These were transported to and from the Godiva site, experiencing the same shock and vibration as the test cores.

Resistance Data

The data obtained and the results of the calculations are given in Table 3. The change ΔR between the initial value R_i and the final value R_f after irradiation is given in percent of R_i. It is evident that the resistance of the control samples fluctuated to the same extent as that of the irradiated samples, i.e., up to about 25%. Further, both positive and negative changes could be found within the same set of either control or irradiated samples. These results tend to indicate a random effect taking place among all the samples. That the above changes are real is shown by a comparison of those changes with the precision of measurement. For example, the greatest ΔR of any irradiated core was 24.4%, while the maximum mean deviation D_R for the averaged readings involved (either initial or final) was only 2.3%; similarly for the control core with greatest ΔR, the values of 22.2% and 1.7%, respectively, were obtained, differing by over a factor of 10.

Effect of Humidity: To determine the cause of the above effects, two factors possibly affecting the resistance measurements were considered: humidity (possibly causing surface conduction) and temperature. To check the first factor, a control core of Type 5 ferrite was re-subjected to a series of resistance measurements inside a desiccator containing $CaCl_2$. The voltage probes remained fixed on the sample for the whole series of measurements. From two to four measurements were made at frequent intervals each day for twelve successive workdays. Again a distribution of values was evident, with R varying over a range of 35% during this period, despite the dry atmospheric condition maintained. Thus, humidity, within the range normally occurring in this Laboratory, was eliminated as a serious factor in the test measurements.

Effect of Temperature: Next, temperature was considered as a possible cause of the fluctuations in the test results. Therefore, another series of measurements on the same sample were made, this time recording the room (sample) temperature during each measurement. (Because of the low currents involved, no heating of the sample occurred.) With the sample still in the desiccator, many measurements over a 3-day period were made at ambient temperatures, the latter being read to 0.5°C with a glass thermometer. Again, ΔR varied over a range of 25%. The above data are shown in Fig. 2 as a plot of logarithm R versus 1/T, where T is in °K. The horizontal lines about each point represent the maximum reading error (±0.5°C) of the temperature measurement. As can be seen, the points, although taken at different times and on different days, fit the straight line within the reading error quite well. This linearity indicates that the above fluctuations in R follow the normal function for resistivity in semiconductors as a function of temperature. This is, in logarithmic form:

$$\ln R = \ln R_o + (\Delta E/k)(1/T),$$

where ΔE is the energy gap, k is Boltzmann's Constant, and T is in °K. Thus, the slope of the line plotted in Fig. 2 is equal to $\Delta E/k$, and from this the energy gap ΔE can be determined. This procedure was carried out and the value of ΔE obtained was approximately 0.6 electron volt. This compares quite well with the literature value of 0.4 electron volt for a $(Ni_{0.5}Zn_{0.5})$-ferrite. (This composition is slightly different from that of the above Type 5 ferrite.) Because of the linearity of the plot, as well as the magnitude of the energy gap determined, it is concluded that the fluctuations in the resistance values measured are caused by the variations in the ambient temperature. Thus, the difference in resistances measured before and after neutron irradiation would depend on which day, as well as on what hour of the day, the measurements were conducted. In order to obtain ΔE more accurately to better confirm the above result, the same sample was remeasured over a considerably greater temperature range than the approximately 4°C range of the daily ambient. This was done to minimize the scattering effect on the plot caused by the temperature reading error. Accordingly, the temperature of the sample was decreased slowly from 127°C to 0°C, and measured with a Wheelco Potentiometer, Model 312, utilizing a chromel-alumel thermocouple placed next to the sample. A plot of the logarithm of the resistance versus 1/T was made. The linear relationship became even clearer than before because of the greater temperature range and smaller reading error. A calculation using the slope of the straight line gave a value for ΔE of 0.4 electron volt, again agreeing with the value given in the literature for the closely related (NiZn)-ferrite mentioned previously.

A calculation was made using this value of ΔE to determine what change in temperature would be required to vary the value of resistance by 25%, the maximum variation experienced by the test samples (both irradiated and control). This was found to be 4°C.

Summary of Resistance Measurements

Therefore, although variations up to 25% in the electrical resistance (or resistivity) of ferrites occurred following irradiation, these changes can be completely accounted for on the basis of normal changes (4°C) in the ambient temperature. The lattice figure is a reasonable one, especially in light of the considerable period (almost a month) between initial and final measurements.

CRYSTALLOGRAPHIC PROPERTIES OF FERRITES

General

The purposes of the crystallographic study were threefold: To determine (1) the formation of crystallographic defects due to neutron irradiation by means of X-ray diffraction line broadening; (2) the redistribution of atoms among the possible lattice sites by observation of changes in X-ray diffraction relative line intensities; and (3) changes in symmetry and size of the crystallographic unit cell by observation of line splitting (extra lines) as well as shifts in positions of the lines. These changes could then be correlated with any observed changes in electrical resistance or magnetic properties due to the neutron irradiation.

Test Samples

Five types of ferrites covering a broad frequency range were investigated. A core each of ferrite Types 1, 2, 3, 4, and 5 were ground down to a powder of sufficient size to just produce continuous X-ray diffraction lines. This was done to prevent fine-particle line broadening. This powder was then subdivided, generally, into two portions which served as irradiated and control samples. The control samples were forwarded to the Godiva site where they remained unexposed and served as site control samples. The samples to be irradiated were kept in paper envelopes and fastened with paper-tape to the hemispherical aluminum framework placed before the Godiva for irradiation.

X-Ray Diffraction Measurements

All the crystallographic measurements were conducted on a Philips Electronics Co. X-ray Geiger Counter Diffractometer, Model 42266, with voltage and current stabilization. Diffraction charts were obtained on a Brown recorder located in the Philips Electronic Circuit Panel, Model 12096, which also contained the low voltage supply, high voltage, dc supply, counters, and ratemeter. The source of the X-radiation used was a Philips X-ray Generator, Model 12045/3, containing an Fe-target X-ray tube with an Mn filter. The standard form of flat specimen of each sample was prepared, and diffraction charts of both the low-angle (front) and high-angle (back) regions of the diffraction pattern were obtained. Each peak of the pattern has an index consisting of three numbers, hkl, called Miller indices.

Lattice Defect Formation

It is known from X-ray diffraction theory that line broadening results from the formation of either lattice defects[3] or fine particles. Since the latter effect is extremely unlikely as a consequence of neutron irradiation, it can be ruled out. On the other hand, the production of lattice defects, such as the expulsion of an atom from its normal position in the crystal to an abnormal interstitial one, is well known to be a result of irradiation in sufficient quantity. The broadening determined for any one line is theoretically sufficient, but four lines were used for statistical reasons to reduce error. To determine this, the Jones method[4] can be used. In this method, the half-width B_o is measured between two straight lines drawn along the slopes on each side of the peak, their intersection being considered the maximum height for the purposes of the measurement. This was done in order to eliminate random variations in the peak height due to background fluctuations, which in turn would cause variations in the measured half-width. In Table 4 is presented the measured half-width of four peaks for each sample of ferrite material, including the control as well as the irradiated samples. They have been measured to within ± 0.01 inch and subsequently converted to angular degrees in terms of the 2θ angle, having a reading error of $\pm 0.02°$. As can be seen from the table, in no case did a half-width for an irradiated sample show a broadening over that of the corresponding control samples exceeding the reading error of $0.02°$. An occasional decrease in half-width was found (opposite effect to that caused by lattice defects) which nevertheless never exceeded $0.04°$ (maximum reading error when taking the difference of two half-width values each with $\pm 0.02°$ error previously mentioned), nor which was demonstrated by the other peaks of the sample. Thus, it was evident that no line broadening had occurred within the experimental error. It was concluded, therefore, that no significant formation of lattice defects had occurred due to the neutron irradiation.

Atomic Redistribution

A change in position of an atom with scattering factor f will result in a change in the intensity of the X-ray reflection. It is for this reason that a redistribution of atoms during the neutron irradiation of this investigation may be hoped to be seen. The practical limitations of this method in the case at hand are quite severe, however, inasmuch as the spinel ferrites are composed principally of the transition elements of the first series, all differing only rather slightly from each other in terms of scattering factor f. The maximum change in f in going from Mn through Fe, Co, Ni, Cu, to Zn in this transition series is only about 25%. The exact limit of detectability of the amount of redistribution occurring differs from ferrite type to ferrite type depending on the composition and distribution of the metal atoms in each case, and has not been determined. However, any gross redistribution of atoms in any of the ferrites would be detected, and conversely any significant change observed in the relative intensities of the diffraction peaks could be ascribed to this cause. Correlative to this would be a change in magnetic properties, such as the saturation flux density and remanent flux density.

Table 5 lists the relative intensities I_{rel} of the various diffraction peaks (hkl) for the control and irradiated samples. The relative intensities of the lines in the front region were calculated on the basis of the strongest peak in the front region (the 311 peak) having an intensity of 100, and similarly for the back region using the strongest line in that region (553/731 peak). This was done to account for changes in the diffractometer slit system for θ greater than 90°, i.e., larger slits were used for peaks with hkl's from 620 to 800. Each intensity reading was obtained from the intercept of two straight lines drawn along the slopes of each diffraction peak, and the background level then subtracted out. As can be seen, the difference in the relative intensities of corresponding peaks for the control and irradiated samples was small, the highest value of ΔI_{rel} being 6 in the front region (i.e., for hkl's between 111 and 440, inclusive). Generally, the ΔI_{rel} values were considerably smaller. This difference of 6 would correspond to ±3 in the readings for the relative intensities of the control and irradiated samples, the latter figure being considered a reasonable reading error for X-ray diffraction peak intensities. In the back region, differences generally were small but ranged up to a ΔI_{rel} of 8, or ±4 in each reading. Again, for the backregion this reading error is not considered excessive in view of the fourfold increase in the range of background fluctuations attributable to the much larger slit system normally used in the back region. Further, it should be remembered that the relative intensities of the peaks in the back region are normalized to one of the lines in the back region, rather than to the strongest line of the whole diffraction pattern. This has the effect of greatly increasing the apparent I_{rel} as well as the ΔI_{rel} values for the back-region peaks, in fact by about a factor of 6, so that the maximum ΔI_{rel} value found (i.e., 8) would amount to about 1 when considered on the same scale as the front-region peaks. Thus, within the error of measurement, no significant change ascribable to neutron irradiation was detected, and therefore no change in atomic distribution was determined.

Lattice Symmetry and Size

The lattice symmetry and size properties were also observed and recorded. The spinel structure of ferrites is of the most symmetric type, i.e., in the cubic class. This means that the interaxial angles of the lattice are all 90°, and the three axial lengths (lattice constants) are all equal. A change in any of the angles, as well as any in the ratios of the axial lengths, would incur the presence of new diffraction peaks in the pattern. For small changes these would be visible as a so-called splitting of the usual peaks. These effects were sought in all the diffraction patterns but were never observed. Thus, it can be concluded that no significant lattice symmetry changes were incurred by the neutron irradiation.

To detect any changes in the size of the crystallographic unit cell, the positions of the 533, 642, and 553/731 peaks for both irradiated and control samples were measured to ±0.01°(2θ) and were then compared. More than one peak was observed for statistical reasons only, since theoretically if one line would shift position then all should. The 2θ-angular position of each peak was obtained from the intercept of two straight lines drawn along the slopes of the peak, in order to minimize irregularities due to the background. The results are shown in Table 6. Although differences $\Delta(2\theta)$ between corresponding peaks of the irradiated and control samples ranged up to 0.05°, these differences were generally not consistent in direction for all three peaks, indicating that they are random fluctuations due to background, etc. Only one sample showed consistent differences (in direction), but the greatest difference shown for any of the three peaks was 0.03°, which is nearly equal to the total reading error of ±0.02° due to the subtraction of two quantities each with a reading error of ±0.01°. (Even this 0.03° difference lies within the 0.05° range of fluctuations found for all the other samples and considered to be the limit of reproducibility in the experiment.) Thus, no significant changes due to neutron irradiation within the experimental error were found in the crystallographic unit cell size of any of the ferrites investigated.

Summary of Crystallographic Study

No irradiation effects could be found in any of the crystallographic properties measured.

CONCLUSIONS

The results of the separate magnetic, resistivity, and crystallographic studies were in agreement in finding that pulsed high-intensity neutron irradiation of the intensity and total dosage employed had no significant long-term effects on the commercial ferrites investigated.

RECOMMENDATIONS

Although the variety of types of commercial radio-frequency ferrites investigated was quite representative of the compositions generally used by all manufacturers in the field, it would not obviate the investigation of other commercial ferrites. Since various manufacturers employ different additives having varying capture cross-sections, each ferrite type should be considered separately.

Moreover, the fortunate lack of long-term effects in the above ferrites does not preclude transient effects during the neutron exposure, the latter measurement requiring different equipment and testing procedure.

Since irradiation effects are known to be dependent on the total dosage for one thing, any knowledge desired on the long-term effects that might correspond to a larger nuclear explosion would have to be gained from another investigation similar to that described herein.

Also, the radiation spectrum from an actual nuclear burst might well be at variance with that of the Godiva reactor, and therefore could have a rather different effect on ferrites. This would seem to suggest then that a more realistic exposure of the material should be investigated.

Finally, any further investigations of radiation effects on ferrites or many other magnetic materials should employ a procedure which, preferably, eliminates temperature as a variable in the magnetic measurements.

REFERENCES

1. Comprehensive Bibliography, Final Report, Part II, Contract AF 19(604)-4141, 15 June 61, Stanford Research Institute, Menlo Park, California.

2. P. P. Cioffi, Rev. Sci. Instr. 21, 624 (1950).

3. A. R. Stokes and A. J. C. Wilson, Proc. Phys. Soc. 56, 174 (1944).

4. F. W. Jones, Proc. Roy. Soc. A 166, 16 (1938).

APPENDIX

Precision of Q-Meter Measurements

Reliability: To check the reliability of the Q-meter, a Standard Q-Coil was measured at three standard frequencies and the values of Q obtained were compared to those given by the manufacturer. These measurements were repeated twice daily for 24 days to ascertain the repeatability of measurement. Average Q values were calculated and found to be: 178 at 0.5 Mc/sec, 228 at 1.0 Mc/sec, and 182 at 1.5 Mc/sec. The manufacturer's values of Q are 179 at 0.5 Mc/sec, 231 at 1.0 Mc/sec, and 198 at 1.5 Mc/sec. The company manual states that the Q-meter is operating satisfactorily if it gives results within ± 7% of the standard values; this criterion was met.

Repeatability: A measure of the repeatability was obtained by calculating the mean deviation in Q at each frequency. This was found to be 1.0 at 0.5 Mc/sec, 0.9 at 1.0 Mc/sec, and 0.9 at 1.5 Mc/sec. These values amount to a relative mean deviation of only about 1/2%. Since these measurements were taken over a 24-day period, this last figure is considered quite tolerable, and indicates a good degree of reproducibility.

Frequency Repeatability: Two additional checks were made on the frequency of the Q-Meter to determine: (1) the repeatability of the frequency setting, and (2) the frequency drift during the course of the usual set of five readings. To accomplish this, a Berkeley Frequency Meter, Model 5570, was connected into the circuit to monitor the frequency. With this instrument, frequency readings were taken to six significant figures. To check the repeatability of the Q-Meter frequency setting, the latter was set up six times to the same dial setting in the usual fashion and the accurate frequency read from the frequency meter. Variations in the frequency with each resetting were obtained but these spanned a range of less than 0.1%. This would incur a change in capacitance of only 0.2% in tuning the circuit to resonance.

Frequency Drift: The second check, to determine the frequency drift during the time required for the usual set of five readings, consisted in setting the Q-Meter frequency accurately and observing the fluctuations with time by means of the Berkeley Frequency Meter. (This was done, as in all the actual test measurements, after a 1-hr warmup period.) Five readings of capacitance and Q were taken during this time, and frequency readings just prior to and following each of these readings were taken. The total range of variation in frequency during the whole period was less than 0.01%, and about one-fifth of this occurred during the course of a single reading. Thus, the effects of frequency drift can be taken as negligible, especially since the initial permeability of ferrites in their optimum range varies very little with frequency.

Precision of DC Hysteresis-Loop Measurements

To determine the repeatability, or precision, of the recording dc hysteresis-loop tracer over a period of time, a typical ferrite core was remeasured each day for seventeen days in an air-conditioned room where temperature was controlled to 21 ± 1°C. The B_m, B_r, and H_c properties were determined. Seventeen-day averages and mean deviations were calculated. The relative mean deviation of the series of measurements was calculated to be 1.1% in B_m, 1.5% in B_r, and 3.6% in H_c. The actual total range of variation measured during the 17-day period amounted to 5.0%, 7.7%, and 11.5%, respectively. (The last variation, for ΔH_c is still less than its total reading error.) Thus measurements before and after irradiation could differ by these last amounts without any neutron irradiation effects being present.

Environmental Effects on Q-Meter Measurements

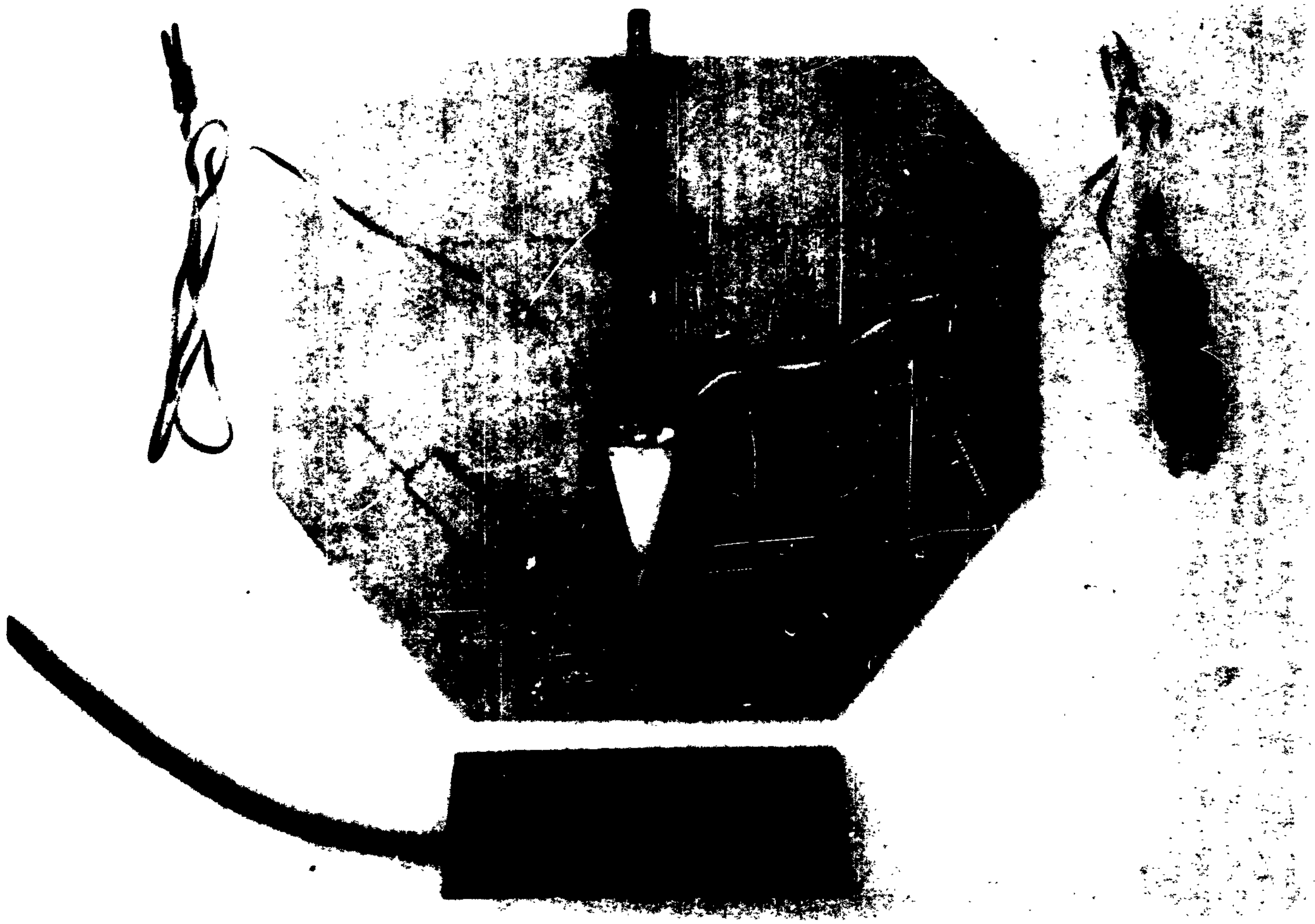
Ambient Temperature: Special checks were made to determine the effect of the sample's environment on the repeatability of measurement. One ferrite core (of Type 12) was kept under the usual ambient conditions in the laboratory, while another ferrite core (of Type 10) was kept in an air-conditioned laboratory where temperature was controlled at 21 ± 1°C. In both cases, the Q-Meter was also kept in the air-conditioned laboratory. In the first case, Q and C were measured each day for fifteen days, five readings of each property being taken at a time and the average calculated. This procedure was followed at three frequencies: 90 kc/sec, 120 kc/sec, and 180 kc/sec. The mean deviation of each set of five readings was also calculated as a measure of the precision of measurement. At 90 kc/sec, C_{avg} (from five readings) varied during the 15-day period over the range from 1292.0 to 1310.4 mmf, or a range of 1.4%. For comparison, the maximum relative mean deviation exhibited by any set of readings on any given day was only 0.3%. At 120 kc/sec, C_{avg} ranged from 727.2 to 737.2 mmf, or 1.4%. The maximum relative mean deviation shown by any day's readings was 0.3%. At 180 kc/sec, C_{avg} ranged from 316.6 to 320.8 mmf, or 1.3%. The maximum relative mean deviation shown on any day was 0.5%. Thus, a relative mean deviation of less than 0.5% is consistently demonstrated for the readings of C on any one day, while day-to-day variations consistently cover a larger range of about 1.4%. The reading error (relative) was calculated to be less than about 0.1% for the two higher ranges of C measured, and about 0.8% for the lowest.

In the case of Q, at 90 kc/sec, Q_{avg} (from five readings) ranged during 15 days time from 38.4 to 40.4, or 5%. With one exception, the relative mean deviation of any day's readings was less than 1.3%, and very often was zero. At 120 kc/sec, Q_{avg} varied from 33.4 to 37.0, or about 10%. Again with one exception, the maximum relative mean deviation shown for any set of readings was 1.4%. At 180 kc/sec, Q_{avg} ranged from 23.2 to 27.0, or 15%. The maximum relative mean deviation exhibited by any one day's readings was 1.8%, with one exception. If one calculates the relative reading error for the values of Q obtained above, it is found that for a maximum reading error of ±1 in Q, relative reading error is as follows: 2.5% for the 90 kc/sec measurements, 2.8% for those at 120 kc/sec, and 4.0% for the above results at 180 kc/sec. These reading errors thus very nearly account for the relative mean deviations in Q obtained above.

Constant Temperature: In the second case, where the ferrite core was kept in an air-conditioned laboratory, the same procedure as outlined above was followed. C_{avg}, measured in this case at 0.3 Mc/sec, varied from 1444.2 to 1456.2 mmf, or over a range of 0.8% during a 15-day period. At 0.6 Mc/sec, C_{avg} ranged from 356.2 to 359.2 mmf, or 0.8%. At 1.0 Mc/sec, C_{avg} varied from 127.6 to 133.0 mmf, or 4%. The maximum relative mean deviations exhibited for the above three measurements were 0.4%, 0.4%, and 1.4%, respectively.

In regard to Q at the first of the above frequencies, Q varied from 162.0 to 166.6, or 3%. The maximum mean deviation of any day was 1.0%. At the second frequency, Q varied from 172.7 to 179.8, or 4%. The maximum mean deviation was 2.7%. At the third frequency, Q varied between 156.0 to 164.8, or 6%. The maximum mean deviation was 0.7%.

Summary: From the data of both experiments, the maximum changes observed during the 15-day period were 4% in C_{avg}, or L, and 15% in Q. That these are real can be concluded from a comparison with the mean deviation (maximum) of 1.4% and 2.7, respectively. Thus, measurements taken before and again after irradiation of samples could conceivably differ by these amounts without the sample suffering any irradiation damage, while changes greater than this amount would be due to irradiation, mechanical shock, etc.

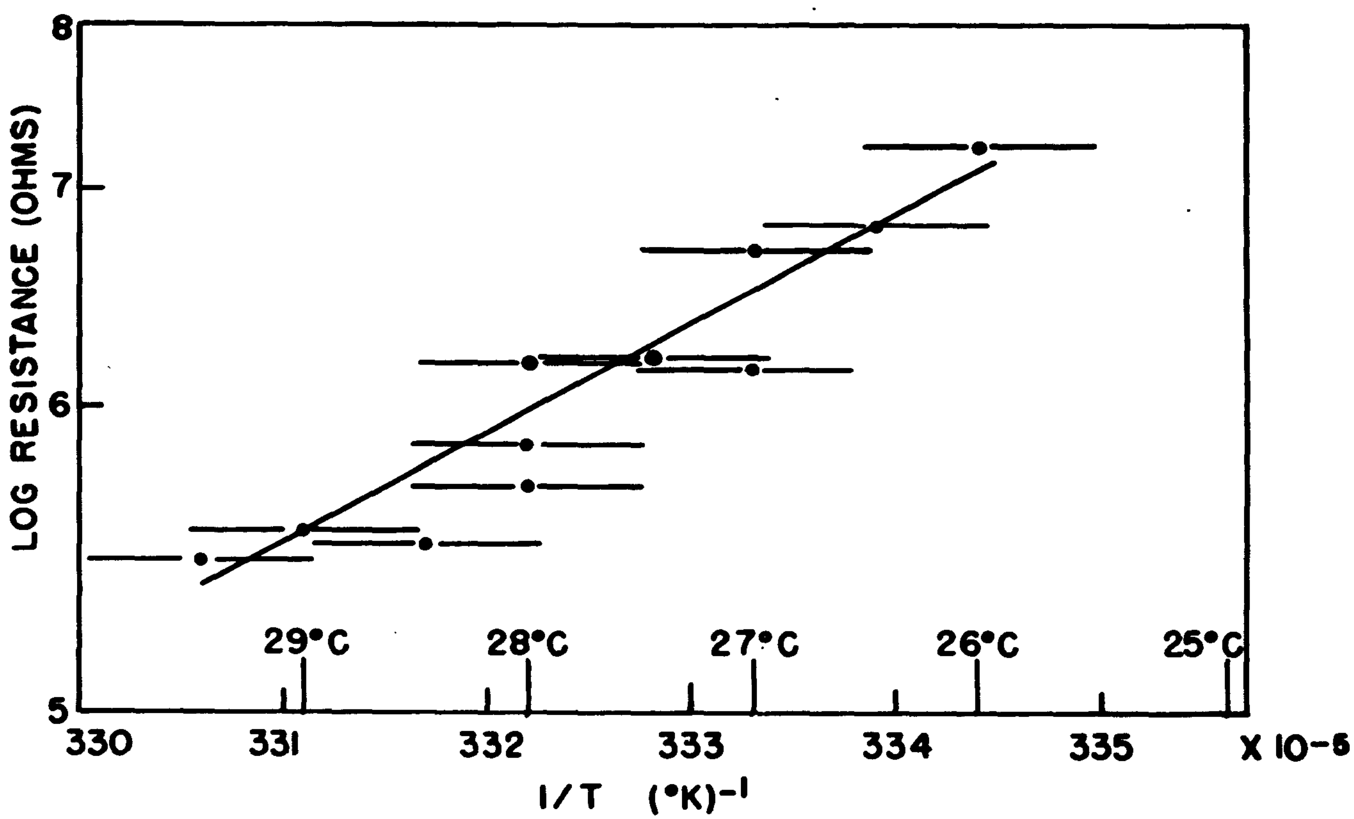


SIGRA/SL-60-806 FORT MONMOUTH. N. J.

JIG, (DISASSEMBLED) FOR APPLYING VOLTAGE PROBES AND CURRENT TO FERRITE TOROIDAL CORE. (EXPERIMENTAL)

FIGURE 1

U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY



DAILY VARIATION IN RESISTANCE WITH AMBIENT TEMPERATURE

FIG. 2

TABLE I. INDUCTANCE AND Q MEASUREMENTS

	FERRITE TYPE 1					FERRITE TYPE 2					FERRITE TYPE 3				
	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)
Test	90	1.8	1.1	4.0	2.0	92	2.9	0.5	-1.7	1.4	6	-0.5	0.2	-4.3	1.3
	126	0.5	0.5	11.8	1.8	126	3.0	0.5	-3.8	1.2	12	-1.9	0	-6.5	1.0
	170	-1.0	0.5	27.3	4.5	170	3.2	0.3	0	1.2	17	-2.0	0.6	-7.3	1.6
Test	90	0	0.3	4.0	2.0	92	2.5	0.6	-4.4	2.4	6	0.2	0.2	-3.7	0.7
	126	-0.5	0.6	11.8	1.8	126	2.2	0.5	-5.4	2.9	12	- 1.0	0.5	-8.8	0.6
	170	-1.8	0.4	27.3	4.5	170	2.5	0.6	-3.7	4.1	17	-4.2	0.8	-12.8	1.7
Site Control	90	0.7	0.4	0	1.7	92	1.8	0.8	-9.4	2.4	6	0.7	0.1	-4.0	1.3
	126	0	0.3	0	0	126	2.3	1.1	-17.9	6.3	12	0	0	-7.2	1.1
	170	0	0.5	7.7	3.8	170	3.4	1.3	-19.0	11.5	17	-1.9	1.0	-8.9	1.2
Site Control	90	0.5	0.3	0	2.0	92	2.1	0.6	-2.1	0.8	6	0.2	0.2	-5.3	0.6
	126	0	0.4	0	0	126	2.3	0.5	-2.5	0.8	12	-0.9	0	-8.5	1.1
	170	1.0	0.5	9.1	2.5	170	1.8	0.7	0	0	17	-1.9	0	-10.9	1.3
Lab Control	-	-	-	-	-	92	2.2	0.6	-2.9	2.0	6	0.7	0.2	-3.3	0.6
	-	-	-	-	-	126	1.4	0.7	0	0	12	1.0	0.3	-5.0	0.9
	-	-	-	-	-	170	-0.9	1.0	-5.0	2.5	17	0	0.6	-6.5	2.0
Lab Control	-	-	-	-	-	92	-0.9	0.7	2.4	1.4	6	-0.2	0.3	-3.2	0.5
	-	-	-	-	-	126	0	0.7	2.9	1.4	12	-0.9	0.3	-7.2	0.8
	-	-	-	-	-	170	0	0.8	4.0	2.0	17	-1.9	0.6	-10.3	0.4

TABLE I. INDUCTANCE AND Q MEASUREMENTS (Cont)

	FERRITE TYPE 5					FERRITE TYPE 6					FERRITE TYPE 7				
	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)
Test	1.0	-0.5	0.1	-1.3	1.0	6.0	0	0.1	-0.3	0.5	0.7	0.1	0.1	1.7	1.0
	1.5	-	-	-	-	9.0	0	0.1	0	0.8	1.0	-0.1	0.1	1.6	0.5
	2.0	0	0.3	0.5	0.9	12.0	0	0.6	0.3	0.6	1.5	0	0.1	2.0	0.5
Test	1.0	-0.8	0.2	-7.9	2.3	6.0	-0.4	0.2	0.6	0.3	0.7	0.2	0.1	1.3	0.2
	1.5	-0.3	0.1	-6.5	0.7	9.0	0	0.3	0	0.6	1.0	0	0.1	1.9	0.5
	2.0	-0.5	0.2	-5.2	0.7	12.0	0	0.3	0.7	0.7	1.5	1.3	0.1	1.0	0.4
Site Control	1.0	-0.3	0.2	-0.6	1.6	6.0	0	0	-2.7	0.3	0.7	0.1	0.1	2.6	0.7
	1.5	-0.3	0.2	-1.0	1.7	9.0	-0.9	0.1	0.6	0.5	1.0	0	0.2	2.5	0.5
	2.0	-0.5	0.2	-2.1	0.9	12.0	0	0.2	1.0	0.7	1.5	0.1	0.1	2.6	0.5
Site Control	1.0	-0.1	0.1	2.2	0.6	6.0	0	0.2	0	0.3	0.7	-0.2	0.1	1.5	0.5
	1.5	0	0.1	1.0	0.6	9.0	-0.9	0.1	-0.3	0.4	1.0	-0.1	0.1	1.0	0.6
	2.0	-0.5	0.3	0.8	0.4	12.0	-1.5	0.8	-0.3	0.5	1.5	0	0.2	1.8	0.6
Lab Control	1.0	-0.1	0.1	6.1	0.6	6.0	-0.4	0.2	0	0.9	0.7	-0.4	0.1	1.7	0.5
	1.5	0.3	0	1.5	0.9	9.0	-0.9	0.1	0	1.0	1.0	-0.3	0.1	1.2	0.3
	2.0	0	0.2	1.8	0.8	12.0	0	0.8	-0.7	0.6	1.5	-0.3	0.1	1.2	0.3
Lab Control	1.0	-0.6	0.4	0.8	3.2	6.0	0	0.3	-0.9	0.5	0.7	-0.3	0.1	1.1	0.4
	1.5	-0.6	0.3	-3.2	3.1	9.0	0	0.2	-0.9	0.3	1.0	-0.4	0.1	0	0.6
	2.0	-0.5	0.5	-4.0	3.2	12.0	0	0.2	-1.3	0.3	1.5	0	0.1	-0.2	0.3

TABLE I. INDUCTANCE AND Q MEASUREMENTS (Cont)

	FERRITE TYPE 8					FERRITE TYPE 9					FERRITE TYPE 10				
	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)
Test	4.0	0.5	0.1	2.9	0.5	300	1.6	0.3	2.5	2.1	0.3	-0.2	0.2	0.2	0.2
	7.0	0.3	0.2	3.5	0.4	400	1.3	0.3	2.5	1.4	0.6	-0.1	0.2	-0.7	0.2
	10.0	0	0.2	6.7	0.3	500	1.7	0.3	3.5	1.6	1.0	0.2	0.2	-0.2	0.2
Test	4.0	0.5	0.2	-0.4	0.5	300	1.5	0.1	0.8	1.7	0.3	-0.2	0.1	2.9	0.2
	7.0	0.4	0.3	1.3	0.5	400	1.9	0.2	1.6	0.8	0.6	0	0.3	2.2	0.2
	10.0	0.6	0.2	3.5	0.5	500	1.8	0.1	3.5	1.2	1.0	0	0.1	4.2	0.3
Site Control	4.0	0.4	0.1	-0.2	0.3	300	2.2	0.5	2.4	2.0	0.3	-1.1	0.1	1.8	0.6
	7.0	0	0.1	1.1	0	400	1.9	0.2	4.6	0.7	0.6	-1.0	0.1	0.7	0.3
	10.0	0	0.2	2.7	0.5	500	1.9	0.2	5.6	0.7	1.0	-1.2	0.2	3.4	0.4
Site Control	4.0	0.2	0.1	0.9	0.3	300	1.9	0.3	2.0	2.0	0.3	-1.0	0.3	0.8	1.1
	7.0	0.3	0.1	1.9	0.3	400	2.1	0.2	4.2	1.4	0.6	-0.9	0.5	-0.3	0.6
	10.0	0	0.2	3.1	0.5	500	1.7	0.4	4.3	1.2	1.0	-1.2	0.6	0.6	0.5
Lab Control	4.0	-0.1	0.2	2.0	0.3	300	2.9	0.1	8.0	2.3	0.3	0.5	0.1	7.1	1.3
	7.0	-0.4	0.2	3.0	0.3	400	2.8	0.2	9.4	0	0.6	0.6	0.3	4.7	0.6
	10.0	-0.6	0.1	4.7	0.3	500	3.2	0.1	9.0	1.6	1.0	1.0	0.2	8.9	0.2
Lab Control	4.0	0	0.1	2.4	0.5	300	2.0	0.1	4.1	1.9	0.3	0.4	0.1	2.7	0.3
	7.0	-0.3	0.2	2.8	0.5	400	2.1	0.2	5.9	1.1	0.6	0.5	0.1	2.8	0.2
	10.0	-0.3	0.4	4.3	0.3	500	2.2	0.2	6.9	1.2	1.0	0.4	0.2	3.9	0.4

TABLE I. INDUCTANCE AND Q MEASUREMENTS (Cont)

	FERRITE TYPE 4*					FERRITE TYPE 5*					FERRITE TYPE 11*				
	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)	FREQ.	$\frac{\Delta L}{L}$ (%)	D_L (%)	$\frac{\Delta Q}{Q}$ (%)	D_Q (%)
Test	150	0.4	0.5	-17.7	0	1.0	-1.0	0.4	-9.7	1.6	55	-3.9	0.8	-5.3	1.5
	225	2.7	0.7	-18.8	2.3	1.5	-1.1	0.3	-7.1	1.4	150	-4.1	0	-9.0	1.5
	300	3.4	0.6	-20.0	2.0	2.0	-1.5	0.3	-8.0	0.7	250	-6.1	1.2	-8.0	1.7
Test	150	1.5	0.7	-11.8	1.8	1.0	0	0.2	-12.3	2.6	55	-4.7	0.8	-12.5	3.5
	225	1.1	0.4	-12.5	3.2	1.5	-0.6	0.3	- 5.4	1.4	150	-4.7	1.2	-11.8	10.0
	300	1.1	0.6	-13.3	0	2.0	-1.0	0.3	- 5.4	1.8	250	-5.6	0.9	- 8.7	15.2
Site Control	150	1.6	0.4	-12.5	6.3	1.0	-0.1	0.2	- 2.3	1.6	55	-1.4	1.4	- 7.7	2.2
	225	1.6	0.4	- 6.7	8.7	1.5	0	0.2	- 5.7	2.3	150	-1.2	1.2	- 8.1	3.0
	300	1.8	0.8	- 7.1	7.1	2.0	0	0.3	- 2.6	1.3	250	-2.6	1.2	- 7.1	4.0
Site Control	150	-	-	-	-	1.0	-0.1	0.3	- 2.1	1.5	55	-1.2	0.9	- 5.1	2.0
	225	-	-	-	-	1.5	-0.3	0.2	- 4.6	1.3	150	-1.2	0.8	- 5.9	1.8
	300	-	-	-	-	2.0	0	0.3	- 5.0	1.3	250	-1.7	0.8	- 7.4	1.5
Lab Control	150	-	-	-	-	1.0	-0.5	0.1	- 2.9	0.9	55	-0.1	0.7	- 5.0	2.4
	225	-	-	-	-	1.5	-0.6	0.2	- 5.3	0.8	150	-0.3	0.6	- 5.3	1.3
	300	-	-	-	-	2.0	-1.5	0.3	- 5.8	0.4	250	-0.7	0.6	- 6.7	1.8
Lab Control	150	-	-	-	-	-	-	-	-	-	55	-0.9	0.7	- 2.7	1.4
	225	-	-	-	-	-	-	-	-	-	150	-0.8	1.0	- 2.7	2.4
	300	-	-	-	-	-	-	-	-	-	250	-1.5	0.7	- 3.8	2.0

* Accumulated Neutron Dosage

TABLE 2

HYSTERESIS LOOP MEASUREMENTS

	Ferrite Type 1 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 2 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 3 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 4 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)
Test	2.3	-7.1	-35	-.07	.05	2.1	-1.5	-11	-.03	.05	0.5	4.8	3.7	.75	.75	0.6	-15.4	-13	-.02	.05
Test	2.3	-10.3	-25	-.05	.05	2.4	3.0	9	.02	.05	1.7	13.8	7.5	1.50	.75	2.5	5.8	0	0	.05
Site Control	2.3	-11.1	-13	-.02	.05	1.8	-1.6	-13	-.03	.05	1.8	-0.8	-10.7	-2.25	.75	2.6	- 5.3	-13	-.02	.05
Site Control	2.3	-14.3	-28	-.05	.05	2.1	-6.1	0	0	.05	1.0	6.3	8.0	1.50	.75	2.6	7.8	15	.02	.05

	Ferrite Type 5 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 6 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 7 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 8 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)
Test	2.6	4.9	5.6	.05	.05	7.5	21.4	0	0	.13	3.3	0	7.7	.25	.5	13.3	14.5	9.4	.94	.63
Test	4.0	6.0	0	0	.05	9.4	14.3	0	0	.13	4.1	0	16.7	.50	.5	10.5	10.7	14.7	1.56	.63
Site Control	2.1	9.1	0	0	.05	7.7	7.1	0	0	.13	-12.8	-7.5	0	0	.5	4.6	5.3	-8.3	-.94	.63
Site Control	2.6	2.4	5.3	.05	.05	9.3	14.3	0	0	.13	-9.2	-4.9	41.7	1.25	.5	8.5	8.2	-3.0	-.31	.63
Lab Control	-	-	-	-	-	-	-	-	-	-	7.5	10.5	15.4	.50	.5	0.9	2.0	-13.5	-1.56	.63
Lab Control	-	-	-	-	-	-	-	-	-	-	-7.1	-3.1	-16.7	-.50	.5	8.3	8.0	-5.9	-.63	.63

	Ferrite Type 9 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 10 $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 4* $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 5* $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)
Test	1.8	15.3	31.6	.12	.25	-1.5	0.7	6.5	.13	.25	2.3	-9.5	-10.0	-.02	.05	3.7	-5.8	0	0	.13
Test	-.9	3.0	0	0	.25	1.6	5.5	5.6	.12	.25	4.1	-6.8	-16.7	-.03	.05	.8	2.0	-3.1	-.06	.13
Site Control	-4.0	6.3	-20.6	-.13	.25	-2.3	0	-5.3	-.12	.25	2.3	-1.6	-10.0	-.02	.05	1.2	3.0	10.1	-.19	.13
Site Control	-2.0	0	0	0	.25	-1.6	0	6.5	.13	.25	2.2	-14.3	-25.0	-.05	.05	0	2.1	-6.0	.12	.13
Lab Control	-1.4	-3.2	0	0	.25	-1.6	0	0	0	.25	3.7	-11.1	-16.7	-.03	.05	2.4	-2.0	0	0	.13
Lab Control	2.0	6.3	0	0	.25	-4.1	-5.6	-5.3	-.12	.25	3.2	-6.6	-16.7	-.03	.05	2.5	2.1	0	0	.13

	Ferrite Type 6* $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)	Ferrite Type 11* $\Delta B_m/B_m$ (%)	$\Delta B_r/B_r$ (%)	$\Delta H_c/H_c$ (%)	ΔH_c (oe)	ΔH_r (oe)
Test	.8	0	-8.7	-.31	.13	0.9	-11.1	0	0	.13
Test	.8	2.8	0	0	.13	1.7	- 1.8	0	0	.13
Site Control	1.6	5.3	0	0	.13	2.3	-29.3	46	.06	.13
Site Control	6.2	0	-3.4	-.12	.13	2.3	-23.4	0	0	.13
Lab Control	6.5	0	-9.9	-.37	.13	2.9	-23.3	0	0	.13
Lab Control	6.7	0	-15.5	-.62	.13	3.5	-14.3	0	0	.13

* Accumulated Neutron Dosage

TABLE 3. RESISTANCE CHANGES IN FERRITES

	$\frac{\Delta R}{R}$ (%)	D_R (%)	$\frac{\Delta R}{R'}$ (%)	D_R (%)	$\frac{\Delta R}{R}$ (%)	D_R (%)	$\frac{\Delta R}{R}$ (%)	D_R (%)
Ferrite Type	(1)		(2)		(3)		(4)	
Test	5.0	3.9	1.3	1.6	18.8	2	0.6	3.6
Test	-5.3	2.6	10.3	2.2	8.1	0.7	-7.0	1.9
Site Control	-3.4	2.1	5.2	2.2	-6.1	3.6	5.3	0.5
Site Control	-8.9	3.2	-13.3	1.7	4.9	1.6	-	-
Ferrite Type	(4-small)		(5)		(6)		(11)	
Test	-3.9	4.3	10.0	2.4	-7.3	2.6	6.1	1.5
Test	-	-	24.4	2.3	10.4	1.5	-4.3	3.1
Site Control	11.8	4.0	6.8	0	22.2	1.7	4.3	0.9
Site Control	-	-	-0.6	0	20.0	1.2	14.5	2.4

TABLE 4. HALF-WIDTHS OF X-RAY DIFFRACTION PEAKS OF IRRADIATED AND CONTROL SAMPLES

FERRITE TYPE	SAMPLE	hkl: 533	642	553/731	800
		HALF-WIDTH B_o (°2θ)			
1	Irradiated	.20	.20	.24	.26
	Control	.18	.18	.26	.28
	B_o	.02	.02	-.02	-.02
2	Irradiated	.18	.18	.24	.24
	Control	.18	.18	.24	.24
	B_o	0	0	0	0
3	Irradiated	.16	.16	.22	.26
	Control	.20	.18	.22	.28
	B_o	-.04	-.02	0	-.02
4	Irradiated	.16	.18	.22	.26
	Control	.16	.18	.24	.28
	B_o	0	0	-.02	-.02
5	Irradiated	.20	.20	.22	.28
	Control	.20	.22	.24	.28
	B_o	0	-.02	-.02	0

TABLE 5 RELATIVE INTENSITIES OF X-RAY DIFFRACTION PEAKS FOR IRRADIATED AND CONTROL SAMPLES

	FERRITE TYPE 1			FERRITE TYPE 2			FERRITE TYPE 3			FERRITE TYPE 4			FERRITE TYPE 5		
hkl	Con. I_{rel}	Irr. I_{rel}	ΔI_{rel}	Con. I_{rel}	Irr. I_{rel}	ΔI_{rel}	Con. I_{rel}	Irr. I_{rel}	ΔI_{rel}	Con. I_{rel}	Irr. I_{rel}	ΔI_{rel}	Con. I_{rel}	Irr. I_{rel}	ΔI_{rel}
111	11	12	1	11	10	-1	24	19	-5	10	9	-1	12	12	0
220	37	36	-1	48	51	3	48	47	-1	38	35	-3	42	43	1
311	100	100	0	100	100	0	100	100	0	100	100	0	100	100	0
222	6	6	0	2	5	3	10	9	-1	6	5	-1	7	5	-2
400	22	20	-2	22	23	1	42	43	1	27	23	-4	20	20	0
422	10	10	0	12	12	0	7	10	3	9	13	4	13	12	-1
511/333	30	29	-1	30	31	1	24	28	4	28	30	2	31	31	0
440	35	35	0	39	36	-3	38	40	2	23	29	6	38	39	1
620	23	23	0	25	26	1	16	20	4	23	26	3	25	22	-3
533	64	63	-1	57	57	0	57	65	8	60	65	5	59	56	-3
444	24	22	-2	18	18	0	22	18	-4	17	16	-1	20	19	-1
551/711	20	19	-1	18	17	-1	17	16	-1	10	15	5	16	18	2
642	41	42	1	36	40	4	33	31	-2	49	48	-1	38	36	-2
553/731	100	100	0	100	100	0	100	100	0	100	100	0	100	100	0
800	44	45	1	45	43	-2	26	24	-2	44	42	-2	42	44	2

TABLE 6 POSITIONS OF X-RAY DIFFRACTION PEAKS FOR IRRADIATED AND CONTROL SAMPLES

FERRITE TYPE	SAMPLE	hkl: 553/731 °(2θ)	642 °(2θ)	533 °(2θ)
1	Irradiated	125.32	119.87	98.66
	Control	125.35	119.86	98.65
	Δ (2θ)	-.03	.01	.01
2	Irradiated	124.85	119.45	98.37
	Control	124.84	119.46	98.36
	Δ (2θ)	.01	-.01	.01
3	Irradiated	122.24	117.11	96.75
	Control	122.20	117.09	96.77
	Δ (2θ)	.04	.02	-.02
4	Irradiated	124.13	118.86	97.92
	Control	124.15	118.85	97.97
	Δ (2θ)	-.02	.01	-.05
5	Irradiated	124.36	119.01	98.06
	Control	124.37	119.03	98.09
	Δ (2θ)	-.01	-.02	-.03

CODE FOR FERRITE TYPES

No.	Commercial Type	Company
1	T-1	Indiana General Corp.
2	0-3	Indiana General Corp.
3	Q-3	Indiana General Corp.
4	H	Indiana General Corp.
5	Q	Indiana General Corp.
6	Q-2	Indiana General Corp.
7	1848	Stackpole Carbon Co.
8	2285	Stackpole Carbon Co.
9	27	Stackpole Carbon Co.
10	9	Stackpole Carbon Co.
11	O-2	Indiana General Corp.
12	23	Stackpole Carbon Co.

DISTRIBUTION

	COPIES
Office of the Assistant Secretary of Defense (Research and Engineering) ATTN:, Technical Library Room 3E1065, The Pentagon Washington 25, D.C.	1
Commanding General U. S. Army Electronics Command ATTN:AMSEL-AD Fort Monmouth, New Jersey	3
Chief of Research and Development Department of the Army Washington 25, D.C.	2
Chief, United States Army Security Agency ATTN: ACofS, G4 (Technical Library) Arlington Hall Station Arlington 12, Virginia	1
Commanding Officer U. S. Army Electronics Research & Development Activity ATTN: Technical Library Fort Huachuca, Arizona	1
Commanding Officer U. S. Army Electronics Research & Development Activity ATTN: SELWS-AJ White Sands, New Mexico	1
Commanding Officer U. S. Army Electronics Research Unit P.O. Box 205 Mountain View, California	1
Commanding Officer U. S. Army Electronics Materiel Support Agency ATTN: SELMS-ADJ Fort Monmouth, New Jersey	1
Headquarters, United States Air Force ATTN: AFCIN Washington 25, D.C.	2

DISTRIBUTION (Cont) COPIES

Rome Air Development Center ATTN: RAALD Griffiss Air Force Base, New York	1
Ground Electronics Engineering Installation Agency ATTN: ROZMEL Griffiss Air Force Base, New York	1
Aeronautical Systems Division ATTN: ASAPRL Wright-Patterson Air Force Base, Ohio	1
U. S. Air Force Security Service ATTN: ESD San Antonio, Texas	1
Strategic Air Command ATTN: DOCE Offutt Air Force Base Nebraska	1
Air Proving Ground Center ATTN: PGAPI Eglin Air Force Base, Florida	1
Air Force Cambridge Research Laboratories ATTN: CRXL-R Laurence G. Hanscom Field Bedford, Massachusetts	2
AFSC Scientific/Technical Liaison Office U. S. Naval Air Development Center Johnsville, Pa.	1
Chief of Naval Research ATTN: Code 427 Department of the Navy Washington 25, D.C.	1
Bureau of Ships Technical Library ATTN: Code 312 Main Navy Building, Room 1528 Washington 25, D.C.	1
Chief, Bureau of Ships ATTN: Code 454 Department of the Navy Washington 25, D.C.	1

DISTRIBUTION (Cont)

	COPIES
Hq. Electronic Systems Division ATTN: ESAT L. G. Hanscom Field Bedford, Massachusetts	1
Chief, Bureau of Ships ATTN: Code 686B Department of the Navy Washington 25, D.C.	1
Director U. S. Naval Research Laboratory ATTN: Code 2027 Washington 25, D.C.	1
Commanding Officer & Director U. S. Navy Electronics Laboratory ATTN: Library San Diego 52, California	1
Commander U. S. Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland	1
Director U.S. Army Engineer Research & Development Laboratories ATTN: Technical Documents Center Fort Belvoir, Virginia	1
Commanding Officer U. S. Army Chemical Warfare Laboratories ATTN: Technical Library, Building 330 Army Chemical Center, Maryland	1
Commander Armed Services Technical Information Agency ATTN: TISIA Arlington Hall Station Arlington 12, Virginia	10
USAEIRDL Liaison Officer Ordnance Tank Automotive Command U. S. Army Ordnance Arsenal Detroit, Center Line, Michigan	1

DISTRIBUTION (Cont)

	COPIES
Commanding Officer Harry Diamond Laboratories ATTN: Library, Bldg. 92, Room 211 Washington 25, D.C.	1
USAEIRDL Liaison Officer Naval Research Laboratory ATTN: Code 1071 Washington 25, D.C.	1
USAEIRDL Liaison Officer Massachusetts Institute of Technology Building 26, Room 131 77 Massachusetts Avenue Cambridge 39, Massachusetts	1
USAEIRDL Liaison Office Aeronautical Systems Division ATTN: ASDL-9 Wright-Patterson Air Force Base Ohio	1
U. S. Army Research Liaison Office Lincoln Laboratory P. O. Box 73 Lexington, Massachusetts	1
USAEIRDL Liaison Officer Rome Air Development Center ATTN: RAOL Griffiss Air Force Base New York	1
Chief, West Coast Office U. S. Army Electronics Research & Development Laboratory 75 South Grand Avenue, Building 13 Pasadena, California	1
USAEMSA Liaison Engineer USASCAJ A.P.O. 343 San Francisco, California	1
Chief Scientist, SELRA/CS, Hq, USAEIRDL	1
USAEIRDA-White Sands Liaison Office, SELRA/LNW, USAEIRDL	1
Corps of Engineers Liaison Officer, SELRA/LNE, USAEIRDL	1
Marine Corps Liaison Officer, SELRA/LNR, USAEIRDL	1

DISTRIBUTION (cont)	COPIES
Commanding General, Army Materiel Command, ATTN: R & D Directorate, Washington 25, D. C.	2
Commanding General, U. S. Army Satellite Communications Agency, ATTN: Technical Documents Center, Fort Monmouth, N. J.	1
Hq, Research and Technology Division, ATTN: RTH, Bolling Air Force Base, Washington 25, D. C.	1
U. S. Army Combat Developments Command Liaison Office, SEIRA/LNF, USAEIRDL	3
Air Force Systems Command Scientific/Technical Liaison Office, SEIRA/LNA, USAEIRDL	1
Commanding Officer, U. S. Army Signal Research Activity, Evans Area	1
Chief, Technical Information Division, Hq, USAEIRDL	6
File Unit Nr. 1, Rm 3D-116, Hexagon	1
Director, Electronic Components Dept., USAEIRDL	1
Dir., Electronic Parts & Materials Division, SEIRA/PE, USAEIRDL	1
Chief, Microwave and Inductive Devices Branch, EP&M Div., SEIRA/SEIRA/PEM, USAEIRDL	30

Army, Ft. Monmouth, NJ-MON 213-63

AD______________ Div.______________

UNCLASSIFIED

Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES by W. W. Malinofsky, J. Newberg, G. C. Sands, September 1962, 24 p., incl. illus., tables, 4 refs. USAELRDL Technical Report 2286
(DA Task 3A99-15-001-01) Unclassified report

Eleven commercial magnetic ferrite types from two companies were investigated for possible long-term effects due to exposure to neutron irradiation simulating a nuclear burst. That is, the materials were exposed to very high intensity irradiation (approximately 10^{17} n/cm²/sec) for a very short period (a pulse of 80 μsec at half-height). The exposed samples, as well as controls, were measured for magnetic, crystallographic, and resistivity changes. Specific magnetic properties examined were L, Q, B_m, B_r, and H_c, as well as electrical resistivity. The specific crystallographic properties investigated were lattice-defect production, redistribution of the metal atoms, and changes in lattice symmetry or size. Magnetic and electrical effects due to ambient temperature, etc., were observed in both control and irradiated cores as random changes. To isolate these effects from irradiation effects, special control tests were ultimately required. After determining the magnitude of these miscellaneous effects and subtracting them out, it was concluded that no changes were observed caused by the neutron irradiation.

1. Ferrites
2. Radiation Effects
3. Magnetic Materials

I. Malinofsky, W. W.
Newberg, J.
Sands, G. C.

II. Army Electronics Research & Development Laboratory, Fort Monmouth, N. J.

III. DA Task 3A99-15-001-01

UNCLASSIFIED

AD______________ Div.______________

UNCLASSIFIED

Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES by W. W. Malinofsky, J. Newberg, G. C. Sands, September 1962, 24 p., incl. illus., tables, 4 refs. USAELRDL Technical Report 2286
(DA Task 3A99-15-001-01) Unclassified report

Eleven commercial magnetic ferrite types from two companies were investigated for possible long-term effects due to exposure to neutron irradiation simulating a nuclear burst. That is, the materials were exposed to very high intensity irradiation (approximately 10^{17} n/cm²/sec) for a very short period (a pulse of 80 μsec at half-height). The exposed samples, as well as controls, were measured for magnetic, crystallographic, and resistivity changes. Specific magnetic properties examined were L, Q, B_m, B_r, and H_c, as well as electrical resistivity. The specific crystallographic properties investigated were lattice-defect production, redistribution of the metal atoms, and changes in lattice symmetry or size. Magnetic and electrical effects due to ambient temperature, etc., were observed in both control and irradiated cores as random changes. To isolate these effects from irradiation effects, special control tests were ultimately required. After determining the magnitude of these miscellaneous effects and subtracting them out, it was concluded that no changes were observed caused by the neutron irradiation.

1. Ferrites
2. Radiation Effects
3. Magnetic Materials

I. Malinofsky, W. W.
Newberg, J.
Sands, G. C.

II. Army Electronics Research & Development Laboratory, Fort Monmouth, N. J.

III. DA Task 3A99-15-001-01

UNCLASSIFIED

AD______________ Div.______________

UNCLASSIFIED

Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES by W. W. Malinofsky, J. Newberg, G. C. Sands, September 1962, 24 p., incl. illus., tables, 4 refs. USAELRDL Technical Report 2286
(DA Task 3A99-15-001-01) Unclassified report

Eleven commercial magnetic ferrite types from two companies were investigated for possible long-term effects due to exposure to neutron irradiation simulating a nuclear burst. That is, the materials were exposed to very high intensity irradiation (approximately 10^{17} n/cm²/sec) for a very short period (a pulse of 80 μsec at half-height). The exposed samples, as well as controls, were measured for magnetic, crystallographic, and resistivity changes. Specific magnetic properties examined were L, Q, B_m, B_r, and H_c, as well as electrical resistivity. The specific crystallographic properties investigated were lattice-defect production, redistribution of the metal atoms, and changes in lattice symmetry or size. Magnetic and electrical effects due to ambient temperature, etc., were observed in both control and irradiated cores as random changes. To isolate these effects from irradiation effects, special control tests were ultimately required. After determining the magnitude of these miscellaneous effects and subtracting them out, it was concluded that no changes were observed caused by the neutron irradiation.

1. Ferrites
2. Radiation Effects
3. Magnetic Materials

I. Malinofsky, W. W.
Newberg, J.
Sands, G. C.

II. Army Electronics Research & Development Laboratory, Fort Monmouth, N. J.

III. DA Task 3A99-15-001-01

UNCLASSIFIED

AD______________ Div.______________

UNCLASSIFIED

Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
INVESTIGATION FOR POSSIBLE LONG-TERM EFFECTS IN FERRITES FROM HIGH-INTENSITY NEUTRON PULSES by W. W. Malinofsky, J. Newberg, G. C. Sands, September 1962, 24 p., incl. illus., tables, 4 refs. USAELRDL Technical Report 2286
(DA Task 3A99-15-001-01) Unclassified report

Eleven commercial magnetic ferrite types from two companies were investigated for possible long-term effects due to exposure to neutron irradiation simulating a nuclear burst. That is, the materials were exposed to very high intensity irradiation (approximately 10^{17} n/cm²/sec) for a very short period (a pulse of 80 μsec at half-height). The exposed samples, as well as controls, were measured for magnetic, crystallographic, and resistivity changes. Specific magnetic properties examined were L, Q, B_m, B_r, and H_c, as well as electrical resistivity. The specific crystallographic properties investigated were lattice-defect production, redistribution of the metal atoms, and changes in lattice symmetry or size. Magnetic and electrical effects due to ambient temperature, etc., were observed in both control and irradiated cores as random changes. To isolate these effects from irradiation effects, special control tests were ultimately required. After determining the magnitude of these miscellaneous effects and subtracting them out, it was concluded that no changes were observed caused by the neutron irradiation.

1. Ferrites
2. Radiation Effects
3. Magnetic Materials

I. Malinofsky, W. W.
Newberg, J.
Sands, G. C.

II. Army Electronics Research & Development Laboratory, Fort Monmouth, N. J.

III. DA Task 3A99-15-001-01

UNCLASSIFIED